Head motion during simulated driving

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Abstract

It is commonly observed that, during curve driving, drivers laterally tilt their head (roll motion) towards the interior of the curve. It is generally supposed that this head behavior would be elicited in response to centripetal forces, drivers aligning their head axis to the resulting gravito-inertial force. However, previous work suggested that this behavior might be less dependant on vestibular than on visual input. In the present study, we tested this hypothesis, using a fixed-base simulator in which, by definition, no centripetal forces are generated during simulated curve driving. Throughout the driving task, subjects were therefore exposed to a constant gravito-inertial force, equal to earth gravity. The experimental task consisted in driving along a winding road, consisting in a randomly ordered succession of curves of various radii, separated by portions of straight lines. In the same time, head orientation was recorded, using an electromagnetic captor, in synchrony with the driving behavior. Results clearly indicate subjects exhibit systematic head roll tilts toward the interior of curves, and that the amount of tilt angle increases with road curvature. These results argue in favor of the hypothesis of visual determinants of head motion during curve driving. We further compare roll head motion to yaw head motion, and conclude that these motions may be part of a global gaze-head visual anticipatory strategy during curve driving.

Introduction

The basic problem of the elucidation of useful visual information for the control of self-motion remains a serious one, notably in the field of car driving, due to the singularities and complexity of the road environment. In the 50's, Gibson (1958) introduced the concept of "optic flow", to describe the transformations of the light pattern (optic array) projected onto the entire retina during self-motion. He suggested that our motion through the environment produces a pattern of optic flow that specifies the properties of our displacement, and that this ambient and continuously transforming layout is processed by active perceptual systems.

Today, this problem remains acute, and alternative sources of useful information for the control of self-motion have been suggested, beyond the global pattern of optic flow (see Wann & Land, 2000, for an overview). Among potential visual cues for the control of self-motion during car driving, Gordon (1966) noted earlier that "[..] when the moving vehicle is aligned with the highway, each point on the road border and lane marker falls on the angular position previously occupied by another point of the border, and the road assumes a *steady state appearance*". Whereas drivers are certainly using optical flow to control their trajectory, they are equally susceptible to use optical stability to steer their vehicle, using edge lines in particular. In that sense, trajectory control could be described as a tracking task, the problem being to maintain visual stability of edge lines. Riemersma (1981) demonstrated that, during simulated road driving, edge line motion was an effective visual cue for the control of heading and lateral control.

In this approach, Land and Lee (1994) introduced new methodological tools, by recording gaze behavior during car driving. They demonstrated that, in curve driving, the eyes tend to fixate the inside edge of the road near a point known as the "tangent" or "reversal" point of the road, which is a singular point on the road edge line, where the inside of the curve visually changes direction. The tangent point's angular position and motion are geometrically linked to the driver's (head) position and motion, and is stable in the visual scene when the observer's trajectory follows the road. Land & Lee's data suggest that subjects pick up useful information for the control of self-motion around this point. In recent psychophysical experiments (Mestre, 2001), we evaluated the ability of human observers to discriminate variations in their direction of self-motion during simulated curvilinear trajectories, as a function of the part of the global optical flow field they were looking at. Results clearly show that trajectory discrimination thresholds are minimal when subjects look directly at the tangent point. As the horizontal direction of gaze departs from the tangent point, thresholds increase significantly. These results confirm the idea that, in tasks such as curve driving, the tangent point of the curve acts as a singularity in the dynamic visual field, enabling optimal perception of the direction of self-motion. We recently (Mestre et al., 2005) revisited Land's original work, in showing that, during curve driving in simulation conditions, the average angular distance between the gazing direction and the tangent point is typically inferior (in average during a curve) to 5 degrees.

Another approach to understand active visual information pick-up consists in studying the role of head movement and orientation during the control of locomotion. Land & Tatler (2001) suggest that the essential part of gaze behavior during curve driving is due to head rotation (they studied yaw movement), while eyes displacement are only transient (during large gaze displacement, the eyes move first, then the head moves and the eyes are finally re-centered in the head) . The functional hypothesis of close links between head orientation and the control of locomotion is also favored by recent studies, suggesting that the head turns toward the future walking direction and the anticipatory nature of such behavior in the locomotor synergy (Hicheur et al., 2005).

Beside yaw motion, roll motion of the head has also been investigated. One may commonly observe drivers tilt their head toward the inside of a curve. The reason of this behavior is not clearly understood. A common explanation is that drivers tilt their head in response to centrifugal forces generated during curve driving, either in order to resist them or as part of a physiological (vestibular-driven) tendency to keep their head aligned with the gravitationally-defined `upright’ direction. In the case of curve driving, two linear accelerations are concomitant: The usual gravity and a centripetal acceleration, this latter depending on the road geometry and the driver's speed. The resultant of both forces is called the gravito-inertial force. It is tilted relative to gravity and the idea is that drivers align their head with the gravito-inertial reference frame. Recently, McDougall & Moore (2005) monitored head motion during curve driving, and typically found that the amount of head roll tilt was inferior to the orientation of the gravito-inertial acceleration. Furthermore, (Zikovitz & Harris, 1999) also studied head tilt during real curve driving. By manipulating driving speed (and consequently the gravito-inertial force), they found that head roll orientation was not significantly dependant of the gravito-inertial force and significantly correlated with the visually-perceived road curvature. They concluded that head tilt reflected the use of a visual reference frame for the driving task.

In the present study, we tried to contribute to the confrontation of these two hypotheses (gravito-inertial versus visual functional determinants of head tilt). We thus studied head behavior in simulation conditions. We used a fixed-base simulator, in which, by definition, no distortion of the gravito-inertial force exists during curve driving. In other words, throughout the driving simulation, subjects were therefore exposed to a peculiar Gravito-Inertial Force (GIF) equal to earth gravity, that is a GIF that is constant both in terms of direction (downwards) and magnitude (9,81 m/s2).

Methods

Subjects. Nine undergraduates, aged between 25 and 32 years, participated in the experiment. They all had normal or corrected-to-normal vision. They were all active drivers, for at least five years. Before the experiment, they signed an informed consent form.

Driving simulator. We used the driving simulator developed by INRETS in collaboration with FAROS company (figure 1). It enables full control of driving scenarios, real-time interactive driving, visual and auditory feedback, and on-line recording of simulated trajectories, for off-line analyses (Espié et al., 2003).

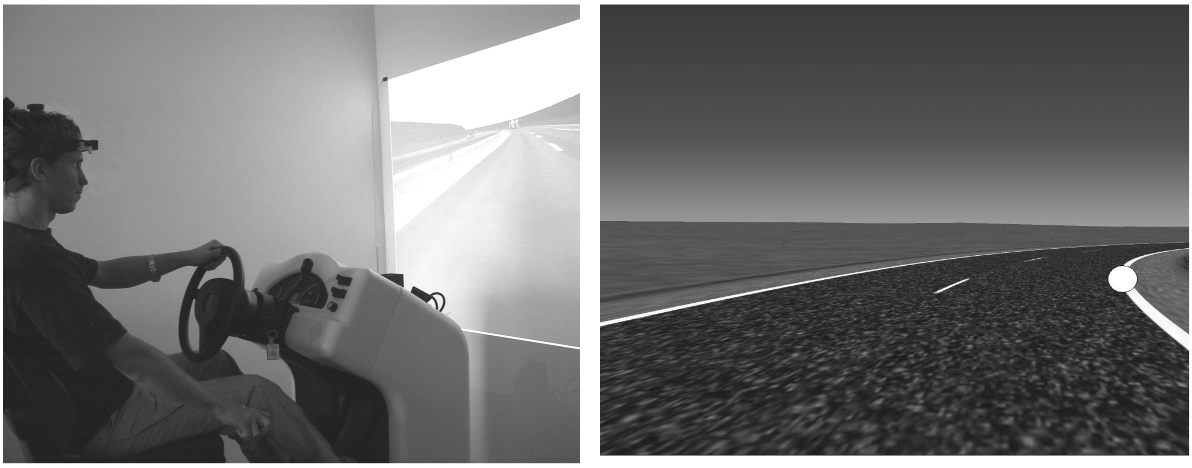

Figure 1. Left: experimental set-up showing the simulator in front of a wide-angle visual scene representing the road environment. Right: snapshot of the visual road environment. The tangent point is represented as a white spot (not visible in the actual task).

Head recording system. Head motion was recorded, in synchrony with simulator data, using a Flock of Bird ® electromagnetic captor, with 6 degrees of freedom. The captor was installed on a helmet on the subject's head (figure 1).

Experimental procedure. In a first step, subjects were trained on the simulator, during three trials on a road with radii of different curvatures, to the left and to the right, separated by portions of straight lines. A trial was completed when the subject drove the simulated vehicle form the start to the finish line of the experimental runway (figure 2). This initial step insured that the subjects got used to this particular simulator and to sharp curve driving. They were instructed to drive at sustained speed without leaving the right lane of the road (3.5 meters wide). Subjects were selected for the actual experimental sessions, provided they could drive the training road in "reasonable" time (as compared to a baseline defined by the experimenters), without running off the road. The experiment itself consisted of three sessions, each lasting about 30 minutes. In each session, three trials were completed. The road environment consisted in a randomly ordered succession of curves of various radii (50, 100, 200, 500 meters), with each radius appearing in each direction (right and left curves, corresponding to positive and negative values of radii, respectively), resulting in 8 curves separated by portions of a straight line (figure 2). The road edge lines were continuous, while the center line was discontinuous (figure 1, right). Head direction was always recorded. It was initially calibrating by asking the subject to align his/her head with a central fixation mark appearing on the screen before the start of a trial.

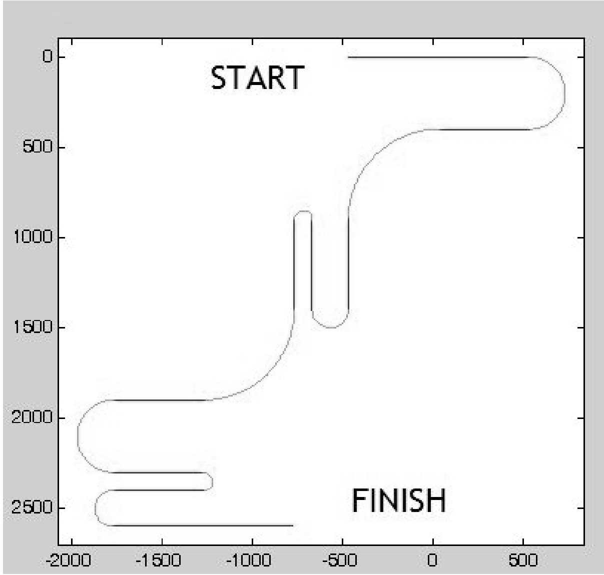

Figure 2. Experimental runway set-up (scale in meters), with 8 constant curvature curves (50, 100, 200 and 500 meters radii, in each direction).

Data Analysis

Data were analyzed for each curve section of the experimental runway, for each subject and each trial (each subject carried out 9 trials). We will present data concerning head orientation during simulated driving along the experimental setup. Individual data were analyzed using Matlab ® software and repeated-measure analysis of the variance (ANOVA). From initial recordings of the driver's behavior and trajectory, we separated the data into 8 curve sections, corresponding to the 8 curves of the runway. We analyzed head orientation as a function of road curvature. For each curve, we computed the average value of head orientation. We never found a significant effect linked to the "trial" (repetition) factor. In other words, subjects did not exhibit a significant learning effect, suggesting that, after training, they were quite good in mastering the simulator's dynamics and controlling their trajectory along the runway, even for sharp curves. We will thus present (in the following figures) data as the average value (and standard deviation) of a given parameter, across trials and subjects.

Results

Head roll angle

Average values for head roll angle (for 9 subjects) are presented on figure 3, as a function of the road curvature. Analysis of variance reveals a significant effect of road curvature (F[7, 56] = 4.46; p<.0005). Head roll is always in the direction of the curve (positive (negative) radii indicate a curve to the right (left), and head roll is in this case positive (negative). Moreover, we can see on figure 3 that head roll angle is linearly related to road curvature. In absolute values, head roll angle increases for high curvatures (being the inverse of road radius, a high curvature corresponding thus to a small radius).

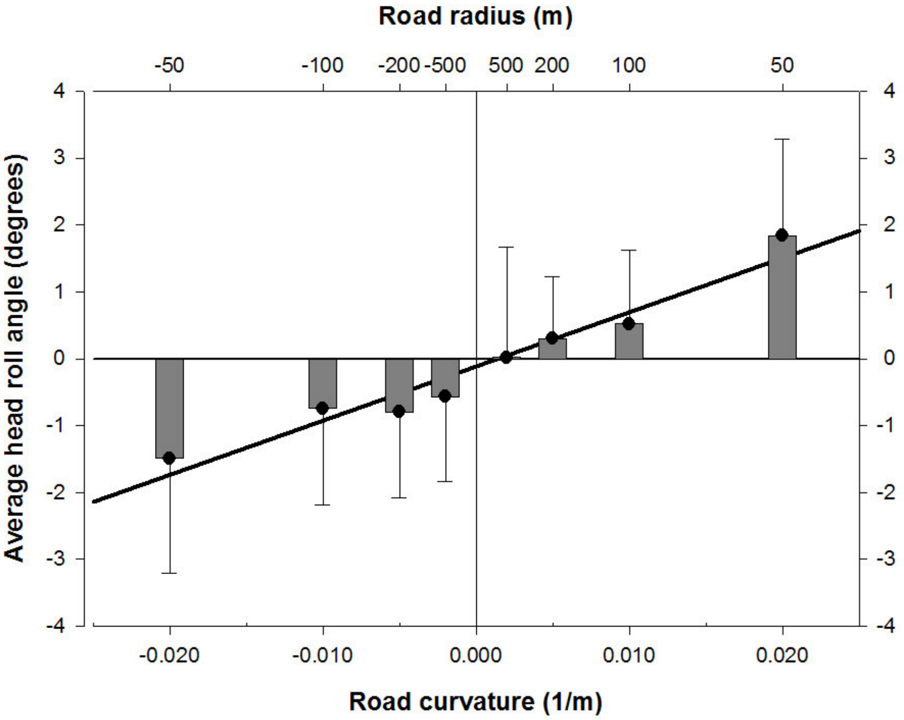

Figure 3. Average values of head roll tilt, as a function of road curvature, with standard deviations. The top axis represents corresponding values of road radius (in meters). Positive (negative) radii correspond to curves to the right (left), respectively. Road curvature is the inverse of road radius. The linear correlation between road curvature and head roll angle is significant (y=81.14x-0.12; r=0.97; p<.001).

These first data indicate the presence of a significant head roll in simulation conditions, being a function of road curvature. In other words, subjects tilt their head toward the interior of a curve while driving and the roll tilt angle is directly related to the sharpness of the curve. However, this systematic behavior is of modest amplitude (4 degrees peak to peak, with the highest values being observed for sharp curves of 50 meters radius).

Head yaw and tangent point angle

We further analyzed head yaw angle, always as a function of the road radius. We observe (figure 4), a pattern quite similar to that observed in figure 3. Analysis of variance reveals a significant effect of road curvature (F[7, 56] = 71.12; p<.0001). Head yaw is always in the direction of the curve (positive (negative) radii indicate a curve to the right (left), and head roll is in this case positive (negative). However, we observe much higher amplitudes of head rotation than with head roll (>13 degrees peak to peak).

In order to further describe this behavior, we compared this pattern with the horizontal angular position of the tangent point (figure 5). We remind the reader that the angular position of the tangent point is dependant on the subject's trajectory, with respect to road geometry. Analysis of variance reveals a significant effect of road curvature (F[7, 56] = 1525.0; p<.00001).

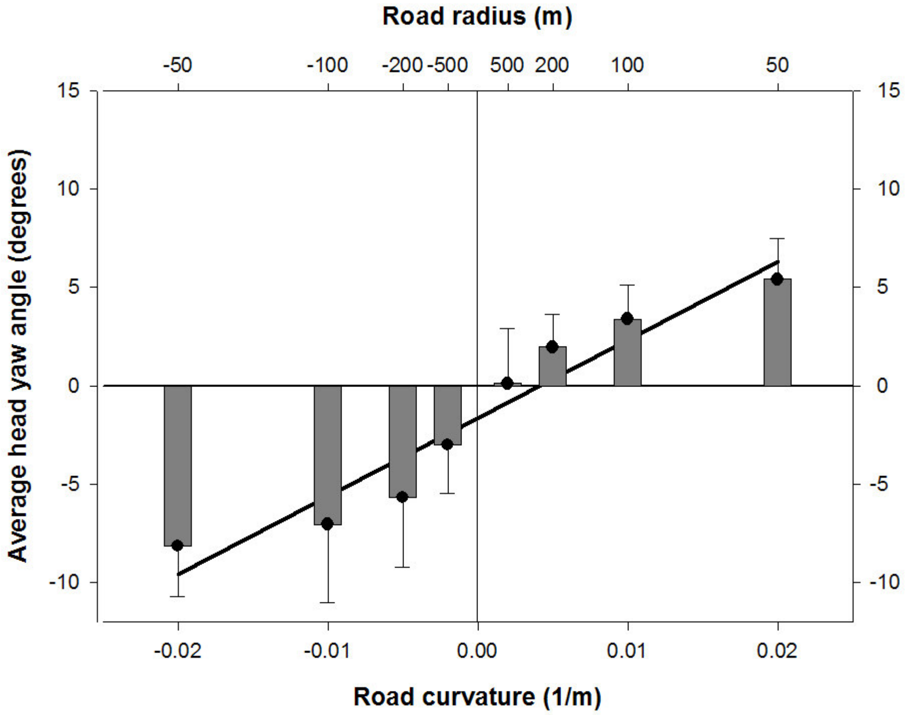

Figure 4. Average values of head yaw angle, as a function of the road curvature, with standard deviations. The linear correlation between road curvature and head yaw angle is significant (y=396.64x-1.65; r=0.96; p<.001).

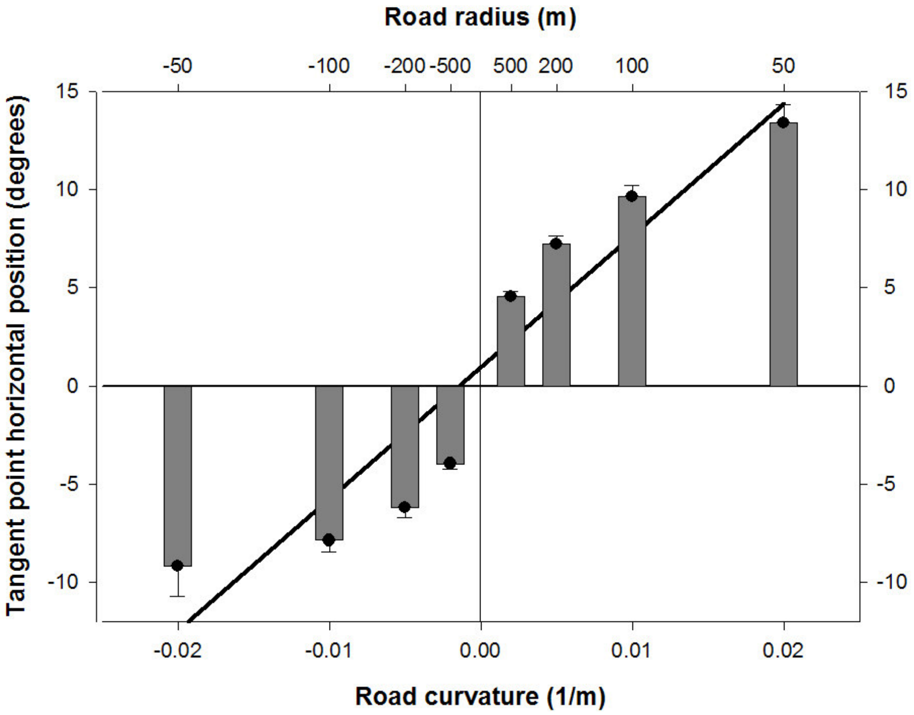

Figure 5. Average values of the tangent point angular position, as a function of road curvature, with standard deviations. The linear correlation between road curvature and tangent point angle is significant (y=671.84x+0.95; r=0.94; p<.001).

The comparison of figures 4 and 5 shows the similarity of both patterns. Three points can be made. First, the magnitude of the tangent point excursion is higher than that of the head yaw angle. Second, standard deviations are much higher for the yaw angle than for the tangent point angle. Finally, standard deviations clearly increase for the tangent point as the road radius is reduced, clearly indicating that the trajectory stability is lower for sharp curves (small radii).

Discussion

In this study, we analyzed experimental subjects' behavior while driving in simulation conditions. We used a fixed-base simulator, which means that subjects had only visual and audio feedback from their driving performance. In particular, they had no driving-related vestibular and/or tactilo-proprioceptive information that would require a dynamic motion platform. In this condition, we focused our analysis on head motion during the task, consisting basically in driving "safely" along a winding road.

If we look back at the data (in reverse order as compared to the presentation of the results above), we first note that the pattern of average values of the tangent point angular position across curves is quite interesting (figure 5). Its values are clearly correlated to road curvature. Its angular (lateral) excursion is on the order of 10 degrees for a road radius of 50 meters. It is thus dependant on the road geometry. What is more interesting is that the tangent point angular position is also related to the subject's trajectory (and instantaneous position) on the road. In this sense, its standard deviation is directly related to the trajectory stability. Without going into the geometrical details of the link between the subject (eye) trajectory and the angular position of the tangent point (TP), we can pretend from figure 5 that trajectory control was obviously harder as the sharpness of the curve increased, but that trajectory control was quite efficient (standard deviation inferior to 2 degrees for curves of 50 meter radii).

As compared to the geometrically-determined indicator TP, head yaw motion exhibits a comparable pattern (figure 4). Across curves, the average angular distance between head orientation and TP position is inferior to 3 degrees. This result is reminiscent of previous data we obtained (Mestre et al., 2005) while measuring gaze orientation during curve driving. It can also be compared to Land & Tatler's study (2001) showing that gaze deviation during curve driving result from an initial movement of the eyes in head, followed by head motion while the eyes are re-centered in the head (figure 4, page 1218 in their paper). This suggests, here again, that subjects orient there gaze toward the tangent point while curve driving, and that the tangent point constitutes a valuable source of information in the matter. Finally, comparing figures 4 and 5 shows that the standard deviation of head yaw motion is higher than the standard deviation of TP angular position. This indicates that, while head orientation is globally dependant on TP orientation, the former exhibits a degree of freedom with respect to TP location. This observation suggests that gazing behavior is not strictly anchored to the tangent point, and that other sources of information might be used, such as edge lines or prospective information about the future of the trajectory. This dispersion of gaze behavior is also apparent in many of Land's studies (Land, 2006), and more analytical work is needed here.

Finally, concerning our original question about the significance of head roll motion during curve driving, results are mixed. First, we found significant head roll motion during curve driving (figures 3), being significantly correlated to road geometry. This result corroborates Zikovitz & Harris (1999) results in actual driving, suggesting that head roll motion is more dependant on visual than vestibular inputs. We observed head roll in a fixed-base simulator, in which no gravito-inertial transformation during curve driving ever existed. However, head roll magnitude is rather small (4 degrees max peak to peak). In Zikovitz & Harris (1999) study, although conditions cannot be fully compared, head roll angles up to 15-20 degrees could be observed. This is quite a difference in magnitude, which might be linked to different experimental conditions, including visual aspects. There is still another possibility: when you compare figures 4 and 3, you may notice the similarity of the patterns. It might well be that head roll motion is functionally and/or biomechanically linked to head yaw motion. The general idea is that multi-axis head orientation in space contributes to active information pick-up, with the combined existence of biomechanical and physiological head-stabilizing mechanisms and anticipatory orienting mechanisms.

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References

Espié S., Mohellebi H., Kheddar A. (2003). A high performance / low-cost mini driving simulator alternative for human factor studies - in proceedings of Driving Simulation Conference (DSC) 2003 North America - Dearborn (USA), October 8-10, 2003 ISSN 1546-5071.

Gordon, D.A. (1966). Perceptual mechanisms in vehicular guidance. *Public Roads, 34*, 53-68.

Hicheur, H., Vieilledent, S. & Berthoz, A. (2005). Head motion in human alternating between straight and curved walking path: Combination of stabilizing and anticipatory orienting mechanisms, *Neuroscience Letters, 383*, 87-92

Land, M.F. (2006). Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research* , *25*, 296–324

Land, M.F. and Tatler, B. (2001). Steering with the head: The visual strategy of a racing driver. *Current Biology, 11*, 1215–1220

Land, M.F. & Lee, D.N. (1994). Where we look when we steer. *Nature. 369*, 742-744

MacDougall, H.G. & Moore, S.T. (2005). Functional assessment of head-eye coordination during vehicle operation. *Optometry and Vision Science, 82, 8,* 706-715.

Mestre, DR (2001). Dynamic evaluation of the useful field of view in driving. Human Factors in Driver Assessment, Training and Vehicle Design, Snowmass Village at Aspen, Colorado USA, August 14- 17, 2001. *Proceedings of Driving Assessment 2001*, University of Iowa, pp 234-239.

Mestre, D.R., Mars, F., Durand, S., Vienne, F. & Espié, S. (2005). Gaze behavior during simulated driving: elements for a visual driving aid. In *Proceedings of the 3rd International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* University of Iowa Press.

Wann, J. & Land, M. (2000). Steering with or without the flow. Is the retrieval of heading necessary? *Trends in Cognitive Sciences, 8*, 319-324.

Zikovitz, D.C. & Harris, L. (1999). Head tilt during driving, *Ergonomics, 42* , *5*, 740-746.